TIMING IN PRIVATE DIGITAL TELECOMMUNICATION NETWORKS

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Abstract

For proper operation of today's large digital private networks, high quality synchronization must be achieved. A general telecommunication performance objective is to maintain long–term frequency accuracy of ten parts per trillion at all synchronous digital equipment in the network. Many times, however, this is not achieved in private networks. Low quality clocks, errored transmission facilities, and incorrectly designed synchronization plans are often cause for poor performance. It is shown that properly-designed private networks can operate with long term frequency averages between ten parts per trillion to ten parts per million.

These performance levels can adversely impact customer applications. The most demanding applications are digital and voiceband data, encrypted voice, facsimile and video. In a typical private network operating at 0.01 parts per million, the user would experience reduced data throughput, dropped encrypted calls, unreadable facsimile pages, or interrupted video transmission dozens of times per day.

The major contribution to poor private network synchronization performance is the interaction of Customer Premises Equipment (CPE) clocks and the network facilities used to distribute timing. The performance of typical CPE clocks and facilities, and their impact on customer applications, are discussed. CPE clock performance issues, along with private network architectural constraints, make synchronization planning extremely difficult. Planning is usually costly and requires specialized expertise.

CUSTOMER EXPECTATIONS

Intelligent digital networks which can consist of the public switched network's facilities and services, as well as customer owned equipment must provide nearly error free performance under a variety of operating conditions. This includes automatic reconfiguration of the network (which may occur under software control, without operator intervention) during normal operations and failure modes.

The robustness of a network can be improved against observable degradation of services during failure modes, if a quality synchronization plan is in place. To attain such a plan, one must consider synchronization performance at each level in the network including:

1. The synchronization performance of the public switched network,

2. The private network's synchronization architecture, and

Report Documentation Page	*Form Approved OMB No. 0704-0188*

1. REPORT DATE **DEC 1992**	2. REPORT TYPE	3. DATES COVERED **00-00-1992 to 00-00-1992**
4. TITLE AND SUBTITLE **Timing in Provate Digital Telecommunication Networks**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **AT&T Bell Laboratories,Holmdel,NJ,07733**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADA267301. 24th Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, McLean, VA, 1-3 Dec 1992

14. ABSTRACT
see report

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

3. The performance of individual, CPE clocking systems.

AT&T has strived to improve the synchronization performance of both the public switched network and CPE [1-5]. Thus, customers can expect and get the best possible error-free performance from digital networks.

NEED FOR SYNCHRONIZATION IN DIGITAL NETWORKS

Synchronization is the means used to keep all the equipment in a digital telecommunications network operating at the same average rate. If the receiving end is to receive and properly interpret the digital signals transmitted over a communications link, it must stay in step, or be synchronized, with the transmitting end. When digital signals are transmitted over a network of digital communications links, switching nodes, and transmission interfaces, all entities must be synchronized. This is known as network synchronization [5].

We refer to the loss or repetition of an entire frame of data as a slip. (The loss or repetition of an entire frame of data along frame boundaries is more accurately called a controlled slip. For purposes of this paper, slips and controlled slips are synonymous). Slips are caused by differences in clock rates within a network and by the effect of transmission-induced impairments on clocks.

The primary methods used to control the slip rate and limit it to an acceptable level are:

1. Operate all clocks in the network at the same average rate.

2. Place buffers at the receiving end to absorb small phase variations.

In the United States, equipment clocks are categorized by ANSI standards according to accuracy and performance level [4]. Stratum 1 clocks have the highest accuracy requirements: stratum 2, 3, and 4 clocks have progressively lower accuracy and performance requirements [5]. Timing references are passed hierarchically from high-performing clocking systems to equivalent or lower performing clocking systems within a network to synchronize many equipment clocks to one, nominal reference frequency. Most of the clocking systems used in the AT&T switched network are stratum 1 and stratum 2. Most clocks found in CPE, such as PBX's and multiplexers, are stratum 4.

However, even when all the equipment clocks are synchronized to a single master clock, it still is impossible to eliminate slips in a digital network. Therefore, synchronization plans are developed to minimize and control the rate at which slips occur. A synchronization plan specifies the timing flow through the network and takes into account equipment performance, facility performance, and network topology.

PRIVATE NETWORK SYNCHRONIZATION PLANNING

Customer digital private networks present additional complexities for synchronization planning. Typically, these networks have diverse architectures; i.e., the equipment and facilities they contain come from multiple vendors and carriers and are interconnected in complex arrangements [7].

In addition, the quality of the clocks in CPE tends to be poor in private networks. Most CPE currently use stratum 4 clocks, which are not designed to transfer timing references between equipment. Consequently, the private network arena is the most difficult one in which to obtain high quality synchronization performance and is the one most susceptible to overall performance problems.

SYNCHRONIZATION ARCHITECTURE

Ideally, timing flow in digital private networks follows the hierarchical source to receiver method. That is, synchronization references are passed from high performing clocks to the low performing clocks. While most private network equipment is usually equipped with stratum 4 clocking systems, some CPE have stratum 3 systems.

Most public switched network services contain traceable, stratum 1 timing (i.e. timing that originates from a stratum 1 primary source). Hence, if the timing source in a private network originates from a traceable, stratum 1, public switched network link, then such timing should be distributed to all CPE throughout the network. Ideally, intra–building timing will be distributed via a hierarchical arrangement. In such an architecture, the best performing clock in a building is used to distribute timing to all office equipment via dedicated lines in the office. The clock is referred to as a BITS (Building Integrated Timing Supply). The BITS receives its timing reference from outside the office. This architecture is used for the AT&T public network. In private networks, a BITS type arrangement is unlikely to happen because most CPE do not have a dedicated timing interface and can only derive timing from a traffic–carrying signal.

Figure 1 illustrates a typical private network location. This location is connected to four other locations in the private network, as well as to three public–switched–network services. Each public–switched–network service contains timing that can be traced to a stratum 1 clock. All equipment at the location requires synchronization, and the diagram shows a reasonable synchronization plan for the site. This plan adheres to the hierarchical timing–flow requirements and permits diverse timing sources into the location.

However, the location does not contain a true BITS architecture. Instead, the location illustrated in Figure 1 has two BITS clocks: the PBX, and the digital cross–connect system (DCS). A BITS architecture offers several advantages:

1. Maximum use of the highest performing clock at the location (without intralocation cascading of timing references)
2. The BITS clock serves as a central point for maintaining synchronization within the location.

Because of implementation problems, private network BITS designs are unlikely. Customer premises lack bridging repeaters for routing timing signals within the site. In addition, some stratum 3 and most stratum 4 CPE systems lack dedicated timing interfaces.

A major focus for any synchronization plan is to overcome topological complexity and constraints. Private networks can suffer from excessive cascading of CPE, lack of diversity of timing references,

and hierarchical conflicts. There may be limited connectivity within the private network and to public switched networks. They may lack provisioning for BITS architectures.

Before a good synchronization plan can be developed for a given network, we must consider these issues in detail. But we must understand that these problems may be compounded because equipment and facility performance will also vary and affect network performance. The stratum 4 clock is one of the consistently poor performers in private networks[7].

CPE CLOCKS

Originally, stratum 4 clocks acted as the CPE receive clock, which terminates timing; they were not designed to transfer timing references between systems. But as the private customer-owned networks have grown more complex, the clocks in CPE (such as PBX's and multiplexers) have been used to transfer timing. Private networks often have long chains of stratum 4 systems through which timing is cascaded.

The main problem with stratum 4 clocks is not their low oscillator accuracy (typically 32 parts per million), but rather their inability to switch cleanly between timing references. If the timing reference for a stratum 4 clock is sufficiently impaired, the clock will switch to its backup timing source, which may be either another timing reference or the clock's internal oscillator. Stratum 4 clocks do not have a phase build-out mechanism that would slowly correct for the phase difference between the previous and current sources of timing. Therefore, the reference switch would cause a phase hit at the CPE's digital interfaces. If this CPE is providing a timing reference to another piece of equipment, the receiving CPE will react to this degradation (which looks like an error burst) by inducing a reference switch of its own. Thus, these impairments will propagate through the chain of cascaded stratum 4 clocks, seriously affecting the network's performance [8].

Stratum 3 and stratum 2 clocks do not suffer from this phenomenon. If a reference switch occurs, these clock systems correct for phase differences between references [6].

Today, digital network standards define a new level of stratum 4 clock that incorporates phase build-out when references are switched. For example, AT&T's TR 62411 (the interface specification for Accunet T1.5 service), which was last published in December 1988, defined an enhanced stratum 4 clock that can be used for timing transfer [8]. This clock, which TR 62411 calls stratum 4, type I, met the requirements for maximum time-interval error (MTIE), which regulates the total phase movement and the rate of change of phase movement of the timing signal under reference-switching conditions. In addition, a new EIA/TIA standard defines the same enhanced stratum 4 system [10].

PRIVATE NETWORK PERFORMANCE

Overall, the typical synchronization performance of a digital private network can be up to 100,000 times worse than the performance of the AT&T network (in terms of frequency accuracy). When new CPE synchronization standards for the telecommunications industry are implemented in private networks, this performance should improve by several orders of magnitude. Generally, a high-quality synchronization plan is needed to minimize the occurrence of slips, error bursts, and phase hits in private networks.

SYNCHRONIZATION PLAN DESIGN CONCEPTS

Some basic concepts need to be considered during the design of a synchronization plan:

1. Whenever possible, it is important to adhere to the hierarchical rules of timing transfer. That is, timing should always be passed from low numbered stratum devices (e.g. stratum 1, stratum 2) to equivalent or higher numbered stratum devices (e.g. stratum 3, stratum 4).

2. Traceable, stratum 1 timing sources need to be used whenever possible, and timing sources should be diverse whenever possible.

3. Timing loops must be avoided. These loops occur when two or more CPE transfer timing to each other and form a loop without a designated master source.

4. The cascading of timing references through CPE should be minimized.

These are some of the fundamental concepts that are the basis of over 6000 rules that AT&T has developed for synchronization planning of digital private networks. The rules have been incorporated into an expert system, called PRINCE–S, that was developed by AT&T Bell Laboratories. PRINCE–S, stands for **PRI**vate **N**etwork **C**omputer–based **E**xpert–system for **S**ynchronization[**9**].

EXPERT SYSTEM FOR SYNCHRONIZATION PLANNING

AT&T developed the PRINCE–S system to mechanize the task of synchronization planning for a private network in a consistent, accurate, and reliable way. AT&T synchronization engineers have used the system to help them design synchronization plans and maintain synchronization networks.

The system generates network maps that specify primary and backup timing reference distribution for each CPE, and estimates the synchronization performance of the network end–to–end (and for each CPE). The system's recommendation represents the best synchronization performance attainable, based on information used to model the network topology, equipment, facilities, and public–switched–network connectivity.

SUMMARY

We have explained how AT&T provides the means to give the best possible synchronization performance in digital customer–owned private networks. This includes consideration of synchronization planning for customer–owned networks and CPE clock–performance issues.

ACKNOWLEDGMENTS

We would like to thank the following for their contributions to the body of knowledge described in this paper: Pablo Alcivar, Jack Amoroso, Ed Butterline, and Elie Khawand.

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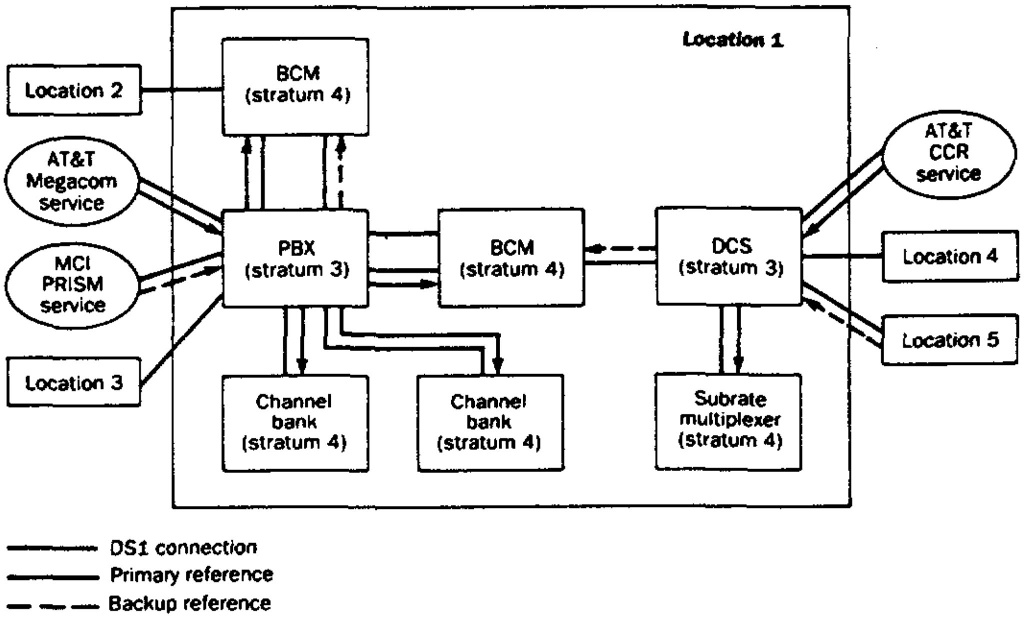

Figure 1. Synchronization plan for all equipment at a representative location in a private network. This location is connected to four other locations in the network and to three public-switched-network services. The timing for each network service can be traced to a stratum 1 clock.

QUESTIONS AND ANSWERS

D. Allan, Allan's Time: This is a broader question than just a private network but perhaps you can address it. If the timing community could provide for telecommunication a clock or clock system which would allow you to synchronize the network with even a broad network say at the 100 nanosecond level forever for all the nodes. What would that mean to telecommunication, if it could be done inexpensively?

C. Near, AT&T Bell Laboratories: It depends upon how inexpensive is inexpensive. It is in a normal carrier environment, for long distance carriers or your locals where they can afford clocking systems, that could be of benefit. If they were in a few (?) range, that is fine. Private networks is where you are going to be getting a much larger customer basis. They are not going to spend that much money. They will spend maybe a $1000.00 for a clock and will not want to spend a whole lot more than that. Sometimes you can get them to spend maybe $5000.00 on a clock but those are cases where you are lucky. If it is in a few hundred to a $1000.00 range and offer that; then they will go for it.

R. Brown: Just my two cents on that Dave. The one thing that I would like to emphasize a little bit from Chris's talk is this is a field with a huge number of players in it. If you look at our specifications I think you people might say that performance is lousy, these guys have got to be dumb if they can not achieve this. We are not dumb, it is just we have a lot of players. We have got different carriers, we have got different vendors. Any circuit that is going to go across the country, you have got local exchange carriers and inter-exchange carriers. Those carriers buy equipment from different vendors and so you are looking at a chain of clocks that is managed by possibly three management entities and the equipment might be built by a dozen different vendors. It might be possible for us to say this is good clock design but we can not force people to implement a design. As far as something at every node, our clients themselves are looking at LORAN receivers. This is a fairly inexpensive thing that might be implemented at every node. Right now their impression is, that is not cost effective. Something has got to be cheaper than to be at every node.

G. Winkler, USNO: This is very right but on the other hand if you have a huge number of customers that is going to bring the price down tremendously. Don not forget all the clock technology today is based on a customer base which can absorb maybe several thousand precision clocks per year. If they can absorb five hundred thousand clocks per year, the price is going to drop as precipitously as the GPS receivers have dropped. Today, only three years after a GPS receiver cost $50,000.00, it is down to $900.00. I would predict to you that a clock which will have one part and 10^{11} capability will cost you less than $500.00 seven years from now, if you have that kind of a customer base and if you will completely turn around all these considerations.

W. Harding, Naval Electronics Systems: That customer base is just right around a corner for you because with the advent of the telephone systems and the pictures that you are going to be able to see years from now by the person that you are talking to on the other end. Also the individual customers as far as VHS communications will all be through satellites. So you are going to have a big base.

R. Kern, Kernco: I have a question. I am new to telecommunications but I have not heard any of you fellows talk about reliability. What is your experience? What MTBF do you need? You can talk about a $100.00 but if it is only going to last a week you are in trouble. Could you comment on reliability or have you guys got standards on that?

R. Brown: I am going to comment on that real quickly and then we will get to Bob's talk and save any other questions to the end. Just on reliability, what we have done at Bellcore is we

write requirements for equipment. We require a lot of duplication of equipment so that no single failure will cause the system to fail. That is really the way we have gone after reliability and it seems to have worked out ok, that you don not get any duplicated failures. As far as specific MTBF numbers, the clocks and the function they are serving are very critical so it has to be very high. The way we have attacked it, is to require duplication of equipment.